A SHUNT METHOD FOR DETERMINING VASCULAR RESISTANCE

R. A. Gareev and T. D. Kim

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One of the principal indices of the state of the vascular system is its resistance to the blood flow, which is determined from the ratio of the pressure difference to the volume blood flow. Resistance to the blood flow depends both on the rheologic properties of the blood and on the parameters of the blood vessels. In fundamental investigations it is often necessary to differentiate between these components. This can be done to a certain extent by the shunt method of determination of specific vascular resistance suggested in this paper.

EXPERIMENTAL METHOD

The method is based on identity of the pressures (and, correspondingly, of their difference) at the arterial and venous ends of an artificial shunt and of the vascular bed to be studied. For instance, according to Hagen's equation ($R \cdot Q = P_A - P_V$), we have $R_s \cdot Q_s = R_b \cdot Q_b$, where P_A and P_V are the arterial and venous pressure, and R_s and R_b the resistance of the shunt tube and of the vascular bed, and Q_s and Q_b the volume blood flow in the shunt tube and vascular bed, respectively. Substituting the resistance according to Poisseuille's equation ($R = 8 \cdot l\eta/\pi \cdot r^4$), in this equation we have $8 \cdot l_s \cdot \eta/\pi \cdot r_s^4 \cdot Q_s = 8 \cdot l_b \cdot \eta/\pi \cdot r_b^4 \cdot Q_b$, or, after oscillations, $Q_s/Q_b = l_b \cdot r_s^4/r_b^4 \cdot l_s = R_b/R_s$, where l is the length, r^4 the fourth power of the radius of the shunt tube and vascular bed, respectively, and η the coefficient of viscosity.

If the parameters of the shunt tube are constant, the ratio of the shunt blood flow to the vascular blood flow must therefore be influenced by the tone of the blood vessels. However, blood is a complex fluid, and because of its particular features the apparent viscosity of blood in a network of blood vessels varies significantly (the Fahraeus–Lindquist effect, aggregation of erythrocytes, and so on). The indices of resistance obtained by the shunt method will therefore include a rheologic component, closely linked with the anatomical and functional characteristics of the vascular bed and its specific features. This index, unlike the total resistance, can therefore be described as the specific resistance.

In the formula for calculating the specific resistance of blood vessels

$$R_b = \frac{Q_s}{Q_b} \cdot R_s \tag{1}$$

the constant resistance of the shunt can be represented as a value obtained from experimental data during the passage of physiological saline through this shunt tube. The same index can be calculated by Poiseuille's equation from values of the length and internal radius of the shunt tube and the viscosity of water (1 cP) in the corresponding physical units.

According to the principles of the method, the shunt tube must satisfy the demands of a rigid hydraulic system, i.e., during a change in intravascular pressure the internal radius and length must remain constant. The resistance of the shunt to a flow of blood of constant composition must not change during a change in the velocity of the blood flow. The internal surface of the shunt must therefore be smooth and it is better if it is siliconized.

The suggested method of determining specific vascular resistance has two alternative methods of recording the initial data: The first is by simultaneous determination of the blood flow in the shunt tube and the vascular bed, the second involves the use of a resistograph [3] and recording of the blood flow in the shunt tube. In that case

$$R_b = \frac{Q_s}{(Q_{tot} - Q_s)} \cdot R_s, \tag{2}$$

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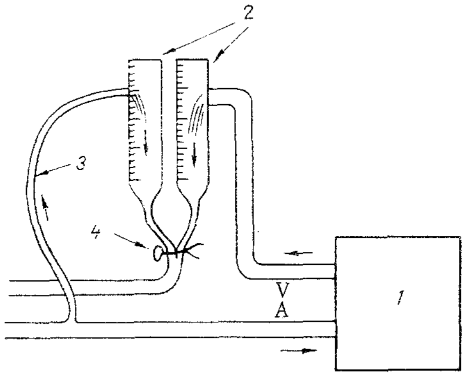

Fig. 1. Scheme of recording blood flow by means of graduated cylinders. A and V) Main artery and vein; 1) vascular region to be studied; 2) graduated cylinder; 3) shunt tube; 4) clamp for stopping flow temporarily.

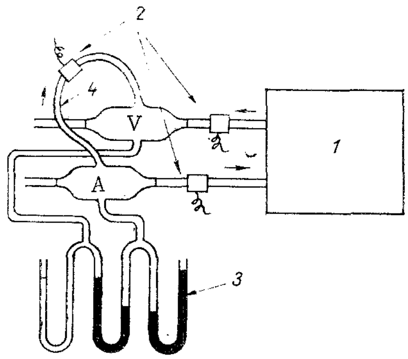

Fig. 2. Scheme of recording blood flow and pressure to calculate total and specific vascular resistance. A and V) Main artery and vein with side tubes; 1) vascular region to be studied; 2) blood flow detectors; 3) manometers: of venous pressure (water), of pressure difference (mercury), and of arterial pressure (mercury); 4) shunt tube.

where Q_{tot} is the output of the resistograph. Since under these conditions the total volume of blood flowing along the shunt tube and vascular bed is equal to the output of the resistograph, changes in capacity of the vascular bed can be recorded [2]. In the first alternative method, two-channel electromagnetic flowmeters can conveniently be used. Under certain experimental conditions a system of graduated cylinders can be used (Fig. 1). The rate of accumulation of blood in the cylinders in unit time (or the absolute values) are substituted in Eq. (1).

To calculate the viscosity of the flowing blood the arterial and venous pressure must be recorded. The total resistance of the vascular bed is calculated from the pressure differences and the blood flow. This index is divided by its specific resistance. The resulting quotient is the index to be used when dividing the index of the total resistance of the shunt tube in the experiment by its constant resistance indicated above.

EXPERIMENTAL RESULTS

Indices of total and specific vascular resistance obtained in six experiments with perfusion of the posterior third of a dog's trunk [1] are given in Table 1. The perfusion fluid consisted of equal parts of autologous blood, dextran, and Ringer's solution. The scheme of

TABLE 1. Specific and Total Vascular Resistance and Its Coefficients of Correlation with Intravascular Pressure during Normothermic and Hypothermic Perfusion of Dog's Limbs (M ± m)

Indices	Temperature of perfusion fluid, °C	
	38	18
Specific resistance of vascular bed, mm Hg/ml/min	0,071±0,05	0,062±0,013
Coefficient of correlation of mean intravascular pressure and specific resistance	—0,622±0,079 $n=10$, $P \geqslant 0{,}05$	—0,796±0,058 $n=10$, $P<0{,}01$
Total resistance of vascular bed, mm Hg/ml/min	0,121±0,018	0,138±0,019
Coefficient of correlation of mean intravascular pressure and total resistance	—0,539±0,095 $n=10$, $P<0{,}1$	—0,788±0,053 $n=10$, $P<0{,}01$
Viscosity of perfusion	1,914±0,210	2,413±0,262

Note: n) Number of variations; P) level of significance.

connecting the blood flow and pressure detectors is illustrated in Fig. 2. In experiments with normothermic and hypothermic perfusion the arterial and venous pressures were changed. The mean intravascular pressure ($P_m = P_A + P_V)/2$ was compared with indices of the total and specific resistance by calculating coefficients of correlation. It will be clear from Table 1 that the coefficients of correlation of the mean intravascular pressure with the specific vascular resistance were more significant than those of correlation with the total resistance. With a fall in the temperature of the perfusion fluid this difference of significance disappeared with an increase in the total and a decrease in the specific vascular resistance. The viscosity of the perfusion fluid was increased by 26%. With a decrease in the temperature of the perfusion fluid under these conditions a tendency was thus observed for the vascular bed to be reduced, and the increase in hydrodynamic resistance was due to an increase in viscosity of the perfusion fluid.

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